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Research Article

Growth and yield of maize in *Eucalyptus* tree alley cropping agroforestry practice in Kafa Zone, Ethiopia

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Abstract

The use of *Eucalyptus* species has long been debated due to both their positive and negative environmental impacts. Findings from previous studies and scientific literature indicate that the effects of *Eucalyptus* on the environment are complex, inconsistent, and highly site-specific. The objective of this study was to evaluate the growth and yield performance of *maize* (*Zea mays* L.) under *Eucalyptus* hedgerow agroforestry practices in Decha Woreda, southwest Ethiopia. The experiment was conducted using a Randomized Complete Block Design with three replications. The study site was selected due to the widespread practice of eucalyptus maize alley cropping, the importance of maize production in the area, suitable agro-ecological conditions, and the need to evaluate the impact of expanding eucalyptus plantations on crop productivity under smallholder agroforestry systems. Maize growth and yield parameters, including plant height, number of cobs, cob weight, 100-seed weight, biomass, and grain yield, were measured. In addition, tree growth parameters such as diameter at breast height and tree height were recorded to assess the effects of different *Eucalyptus* species on intercropped maize. Data were analyzed using analysis of variance, and treatment means were separated using the Least Significant Difference test at the 95% probability level. In the first cropping season, maize grain yield did not differ significantly among treatments; however, a yield advantage was observed under river red gums (*Eucalyptus camaldulensis* Dehn) hedgerows. In the second and third cropping seasons, grain yield differences were significant ($P \leq 0.05$) and consistently declined under *Eucalyptus* hedgerows compared with sole maize cropping. Among the four *Eucalyptus* species evaluated, flooded gum (*Eucalyptus grandis* W.Hill ex Maiden) and Sydney blue gum (*Eucalyptus saligna* Sm.) significantly ($P \leq 0.05$) reduced maize grain yield during the second and third cropping seasons. Regarding tree growth performance, *Eucalyptus saligna* and *Eucalyptus grandis* exhibited greater height and diameter at breast height, while comparatively reduced growth in height and diameter at breast height was recorded for *Eucalyptus camaldulensis* and lemon-scented gum (*Eucalyptus citriodora* Hook.). However, their annual growth rates were not markedly different. The study also revealed no significant effect of *Eucalyptus* species on soil moisture content near the hedgerows, although relatively higher soil moisture was consistently observed under *Eucalyptus camaldulensis* over three consecutive years. Therefore, farmers practicing maize intercropping with *Eucalyptus camaldulensis* in a hedgerow arrangement with sufficient spacing (8 m) between hedgerows can potentially obtain both wood and food from the same unit of land. Nevertheless, appropriate management practices are essential to minimize competition between trees and annual crops, as both are crucial for farmers' livelihoods.

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Key words: agroforestry, allelopathy, diameter at breast height, *Eucalyptus* species, maize yield, total soil nitrogen

Introduction

In Ethiopia *Eucalyptus* was introduced during the reign of Emperor Menilek II (1868–1907) in 1894/95 (Molla et al. 2023). The purpose was to supply fuel wood and construction timber to the new and growing capital city, Addis Ababa. In the 1970s, the plantation area around Addis Ababa was about 15,000 ha while in other parts of the country approximately 76,000 ha of plantations had been established. Between 1975 and 1994, further new plantations were established mainly in urban areas with aid from international donors such as UNSO, SIDA, WFP, and WB (Gebremedhin and Negash 2023). About 55 species of *Eucalyptus* have been grown in Ethiopia, of which the most widespread *Eucalyptus* species include *E. camaldulensis*, *E. citriodora*, *E. globulus* subsp., *globulus*, *E. regnans*, *E. saligna* and *E. tereticornis*. *E. globulus* and *E. camaldulensis* are the major species planted in the highlands of Ethiopia (Birara et al. 2019). In the South region of Ethiopia, *eucalyptus* plantation has long been practiced by smallholder farmers as a fast-growing multipurpose tree grown for fuelwood, construction materials, and income generation, reflecting its widespread adoption in Ethiopian agroforestry systems due to its rapid growth, adaptability, and economic value (Abebe 2005).

However, planting *Eucalyptus* has become a subject for argument because of its both positive and negative ecological effects. The main potential negative impacts focused on its severe competition of growth resources with companion plants particularly the extraction of water resources and soil nutrients. The detrimental effect of *Eucalyptus* plantation on soil total nitrogen, exchangeable Calcium and soil moisture content and P stocks (Guedes et al. 2016; Daka 2023) were reported. Studies conducted in the central highlands of Ethiopia also reported that *E. globulus* depleted soil nutrients (Michelsen et al. 1993; Kindu et al. 2006). Schlönvoigt and Beer 2001 reported that *Eucalyptus deglupta* reduced maize yields by 15 and 58% during the second and the third maize harvests in Costa Rica, respectively. An average of 20–25% yield reduction per unit land area for maize intercropped between up to 10 tree species was reported in Canada when compared to the yield recorded in conventional mono-cropping (Zimmerman et al. 2016). Research results on boundary planting of *E. globulus* in Ethiopian Nitosols showed a significant reduction of wheat yield in the first 8 to 12 m across the tree crop interface (Kidanu et al. 2004). Other studies suggested that *Eucalyptus* released toxic allele chemicals into the soil system mainly through litter decomposition products (May and Ash 1990; Michelsen et al. 1993) and reduced germination and radical growth of chickpeas, field pea, maize, and teff (Michelsen et al. 1993).

On the other hand, other studies showed that light, moistu

L.re and minerals under the canopy of *Eucalyptus* are adequate to support other plant growth (Daba 2016; Yang et al. 2017). Several research results revealed that *Eucalyptus* species are efficient water users, i.e., they consume

less water per unit of biomass produced than other crops, conifers, acacias, and broad-leaved tree species (El-Amin et al. 2001; Yang et al. 2017). Under both moisture and nutrient stress *Eucalyptus globulus* and *E. camaldulensis* grew better than deciduous tree species in Ethiopia (Gindaba et al. 2004, 2005a, 2005b; Albaugh et al. 2013). Another study in Ethiopia showed that land-use change from agriculture to *E. globulus* and *E. camaldulensis* plantation had no adverse impact on exchangeable potassium, total soil nitrogen, phosphorus, and Sulphur at least up to the age of 14.5 years (Bayle 2019). Although people believe that the species would not serve agroforestry purposes, *Eucalyptus* has given the best results when planted as an agroforestry tree with 6 × 1 m spacing under rain-fed conditions (Behera et al. 2024). Good results were recorded when coffee was inter-cropped in spacing 8*8 m spacing of *Eucalyptus* plantations in Costa Rica (Schaller et al. 2003). The use of some *Eucalyptus* trees in agro-forestry is also common in Nigeria and Thailand ((Igboanugo et al. 1990). In the Philippines, widely spaced tree rows intercropping is more profitable and feasible to smallholders than mono cropping (Bertomeu 2011).

The aforementioned research results and scientific literature on the overall impact of *Eucalyptus* trees show complex, inconsistent, and site-specific results. Generally, the effect of *Eucalyptus* may vary within different geographical areas, rainfall regimes and management employed. In recent years, rows of *Eucalyptus* species planted along field borders have become a dominant feature of south and southwest Ethiopia, and maize farming is the dominant agricultural system and is widely grown as a major food and cash crop. Therefore, information on the effect of *Eucalyptus* on the surrounding environment and the level of maize yield reduction in systems with *Eucalyptus* trees is very important for increased awareness and improved land management intervention in the study area. With this context, the present study was aimed at i) assessing the effect of four *Eucalyptus* tree species including *Eucalyptus camaldulensis*, *Eucalyptus citriodora*, *Eucalyptus grandis* and *Eucalyptus saligna* planted in hedgerow arrangement on the grain yield of intercropped maize ii) evaluating the allelopathic effect of the species on maize seedling growth in Decha district of Kaffa zone, southwest Ethiopia.

Materials and methods

Description of the study area

The study was conducted at Modiyo kebele in Decha district Kaffa zone, southwest Ethiopia. The study site was selected because it represents an area with extensive eucalyptus-based agroforestry practices and diverse altitudinal conditions typical of the region (Fig. 1). The district is located within the latitude of 07°8'-07°26' North and longitude of 35°53'-36°36' East. The altitude of the study area ranges from 500 to 2300 masl consisting of a highly dissected plateau with flat and undulating terrain (Alemayhu and Yakob 2020).

According to the harmonized soil map of Africa (Dewitte et al. 2013), the major soil groups are nitisols, acrisols, leptosols, regosols, cambisols,

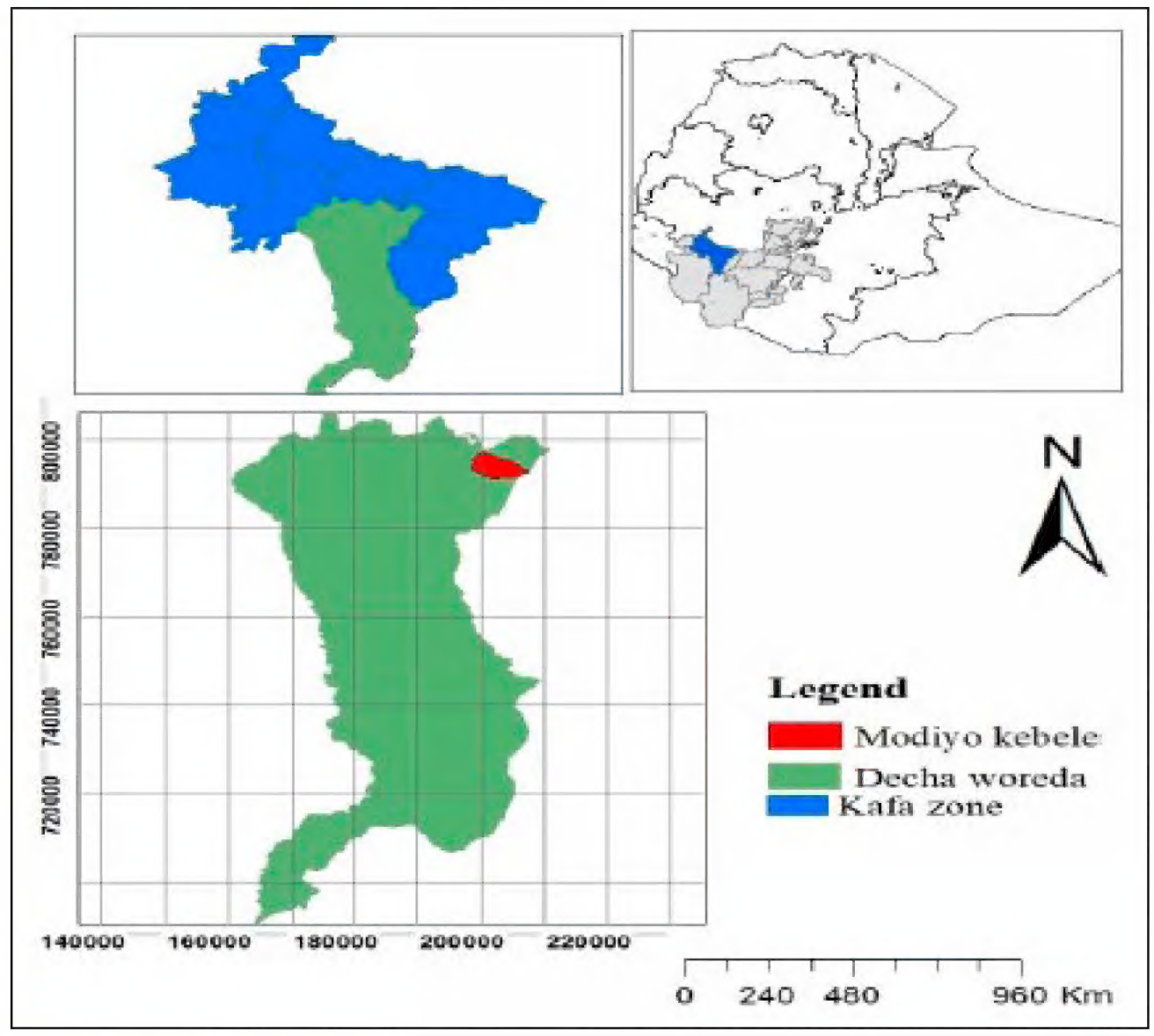

Figure 1. Map of the study area.

Table 1. Some soil physicochemical properties of the studied site in the Decha district of Kaffa zone, southwest Ethiopia.

Soil properties	Values	Soil rating
% OC	3.76	High
% OM	6.48	High
%TN	0.32	High
Av P (Ppm)	12.06	Low
pH soil H_2o 1:2.5	5.2	Strongly acidic
Textural class	Clay	

Note: OC-Organic carbon, OM-Organic matter, TN-Total nitrogen, Av.P- Available phosphorus.

and vertisols. Nitisols are agriculturally the most important and dominant type of soil. Some physical and chemical characteristics of the soil at the study site are indicated (Table 1). The study area experienced one long rainy season, lasting for 8 months from March to October, and the wettest months are between May and August. The mean annual rainfall ranges from 1710 mm at Bonga station to 1892 mm at Wushwush station. Over 85% of the total annual rainfall, with mean monthly values in the range of 125–250 mm, occurs in the 8-month-long rainy season. The mean temperature is 19.4 °C at Bonga and 18.1 °C at Wushwush station (Demisse 2015). The vegetation of the area belongs to the Afro-montane rain forest (Friis 2010). In southwest Ethiopia, particularly in the study area, the dominant plant species are *Schefflera abyssinica*, *Erythrina abyssinica*, *Syzygium guineense*, *Albizia gummifera* and *Croton macrostachyus*.

Plant material and nursery management

Seeds of *Eucalyptus* species were obtained from Forest Research Center, Addis Ababa. Seedlings for the trials were raised at the Keyakela nursery site in the Kaffa zone between December–June 2012 close to the study sites. Nursery sowing of the multipurpose species was done on seedbeds and after germination the seedlings were pricked out into white polythene tubes. A bamboo shed was set up immediately after pricking out to provide shade and was removed as necessary. While in the nursery the seedlings were watered twice per day during the morning and evening except on days when it rained. This was, however, reduced to once every other day three weeks before planting. Weeds were removed on detection and root pruning was done whenever roots outgrew the polythene.

Experimental design and approach

Two separate experiments were conducted both in the field and nursery. The first experiment was conducted from 2013 to 2016 to evaluate the effect of *Eucalyptus* tree species on the grain yield of intercropped maize laid out in a randomized complete block design with five treatments and three replications. Treatments were; T_1 (control): maize mono-cropping, sown at 30 cm within-row spacing and 75 cm between rows spacing, T_2 (trees of *Eucalyptus camaldulensis* on hedgerows at 0.5 m x 10 m, with maize inter-planted in the 10 m wide alleys), T_3 (trees of *Eucalyptus citriodora* on hedgerows at 0.5 m x 10 m, with maize inter-planted in the 10 m wide alleys), T_4 (trees *Eucalyptus grandis* on hedgerows at 0.5 m x 10 m, with maize inter-planted in the 10 m wide alleys) and T_5 (trees of *Eucalyptus saligna* on hedgerows at 0.5 m x 10 m, with maize inter-planted in the 10 m wide alleys). Plots having the size of 300 m^2, (15 m along the contour line and 20 m along the maximum slope gradient) consisting of three rows of *Eucalyptus* with thirty-one trees per line were established at the trial site. The plots were separated by guard areas of 8 m to avoid the influence on adjacent plots. The first maize cropping was carried out after nine months of tree planting and was continued for two consecutive cropping years. All other maize farming operations were performed manually following local practices. Every cropping season, maize variety, BH660, was sown into furrows at a spacing of 30 cm b/n plant and 75 cm between rows. The maize crop was fertilized at the recommended rate (100 kg DAP and 100 kg Urea). Fertilizer was applied only to the crop but trees might have probably benefited from the fertilizer applied to the maize. Ring weeding around tree seedlings was conducted for one year (Fig. 2).

The second pot experiment was conducted in a nursery at Bonga Agricultural Research center. Leaf biomass was collected from established eucalyptus hedgerows at 24 and 36 months after planting to evaluate the allelopathic potential of *Eucalyptus* species on germination and early growth of maize crops. The fresh green leaves of four *Eucalyptus* tree species (*E. camaldulensis*, *E. citriodora*, *E. saligna* and *E. grandis*) were collected from the experimental site and washed with water, and chopped manually. 500 g of the chopped leaf was soaked in 2 liters of water using plastic tubes for 24 hours and stirred frequently. The extract was filtered through a double-layered

Figure 2. Layout of field experiment for evaluating maize yield under eucalyptus hedgerows.

cloth. Soil samples were taken from different spots under a canopy of four *Eucalyptus* tree species except for the control which was taken from outside the canopy and was filled to the respective pots. Five treatments were replicated four times in a completely randomized design. Five seeds of maize variety BH660 were sown in each pot. The aqueous extracts of four *Eucalyptus* species were applied to the respective and one control pot was irrigated with tape water. The soils in pots were kept moist throughout the experiment by applying aqueous extract and water to the respective pots. The number of seeds germinated was counted daily till the completion of germination. To assess the growth of the maize plant, seven days after seeding the plants were thinned and only three healthy plants were kept in each bag. After 14 days, the plants were harvested for fresh weights of shoots and roots. They were then kept in paper bags and tagged properly and air-dried for two weeks for taking the dry weight of shoots and roots.

Data collection and analysis

To evaluate the effects of *Eucalyptus* tree species on the growth and yield of maize, plant height, and the number of cobs, cob weight, 100 seed weight, and grain yield data were measured and two plant samples were also taken from each of the upper, middle and lower alley zones to measure total biomass of maize.

To evaluate the annual growth performance of eucalyptus trees diameter at breast height (DBH) and tree height were recorded until the age of 36 months. To estimate the wood resource from *Eucalyptus* trees, the basal area was also calculated as $BA = \pi d^2/4$, where d = diameter at the breast height.

For allelochemical effect evaluation; germination rate, plant height, collar diameter, number of leaves per plant, fresh biomass, root & shoot length, root & shoot fresh weight, and root and shoot dry weight data were calculated. The germination percentage was calculated following (Saxena et al. 1996) as:

$$\mathrm{GC}(\%) = (\text{No of germinated seeds}/\text{Total No of seeds sown}) \times 100$$

Shoot length (cm) was measured with a m rod and the measurements were taken from the stem joint to the tip of the terminal leaf. Root length (cm) was measured with a m rod and the measurements were taken from the root joint to the tip of the tap/main root. Collar diameter (mm) of the crops were determined using a caliper. After the different organs were separated to shoot and root biomass, they were kept in paper bags and tagged properly. Wet and dry weights of the biomass were measured using scientific electrical balance.

Statistical analysis

The collected data were subjected to statistical analysis software (SAS version 9), analysis of variance (ANOVA) was used to analyze variations among the treatments and a 95% probability level was considered for significance declaration. The least significant difference (LSD) tests were used to identify mean differences.

Results and discussion

The effect of *Eucalyptus* tree species on maize grain yield

Maize grain yield variation among the treatment was not significant in the first cropping season (2014). Significant ($p \leq 0.05$) yield reduction was recorded in the second (2015) and third year (2016) of intercropping. The highest reduction of maize grain yields was recorded by plots with *E. saligna* ranging from 49% in the second cropping season to 72% in the third cropping season, followed by *E. grandis* ranging from 30.5% in the second cropping season to 57% in the third cropping season compared to mono-cropping (Table 2). Similar effects of *Eucalyptus saligna* were reported in Southern Rwanda maize grain yield which reduced from 2.5 t/ha in open fields to 0.5 t/ha within 10.5 m of the woodlots (Mugunga et al. 2017; Onyewotu et al. 1994). Onyewotu et al. (1994) also revealed the competitive effects of *Eucalyptus* shelterbelt on an adjacent millet (*Pennisetum typhoides* Stapf & C.E.Hubb.) that yield from crops grown very close to the belt were reduced because of competition with the trees for light, soil moisture and nutrients, and shading. Plots with

Table 2. Grain yield and hundred seed weight of maize under *Eucalyptus* species in three consecutive years of the study period in Decha district of Kaffa zone, south-west Ethiopia.

Treatments	Grain Yield (t/ha) (Mean ± SD)			Hundred Seed Weight (g) (Mean ± SD)		
	Year			Year		
	2014	2015	2016	2014	2015	2016
T_1(Sole maize)	2.46 ± 0.35	4.33 ± 0.79a	4.66 ± 0.67a	40.1 ± 1.1	47.5 ± 3.4	34 ± 2.9
T_2(*E. citriodora* with maize)	1.93 ± 0.77	3.67 ± 0.95ab	2.45 ± 1.1bc	40.3 ± 2.2	51.2 ± 1.3	34.2 ± 4.7
T_3(*E. camaldulensis* with maize)	2.98 ± 0.17	4.78 ± 0.26a	3.6 ± 1.2ab	39.4 ± 1.1	47.8 ± 1.8	34.1 ± 2.8
T_4(*E. grandis* with maize)	2.32 ± 0.32	3.01 ± 0.26bc	2.01 ± 1.2bc	41 ± 0.88	45.7 ± 3.9	35.8 ± 2.3
T_5(*E. saligna* with maize)	1.78 ± 0.99	2.22 ± 0.22c	1.29 ± 0.34c	39 ± 2.2	42.9 ± 3.3	37.2 ± 2.1
CV (%)	34	18.1	39	4.1	6.2	8.8
$LSD_{(p = 0.05)}$	NS	1.184	2.01	NS	NS	NS

Note: Mean values with different letters are statistically different at α = 0.05.

Table 3. Biomass yield and plant height of maize under *Eucalyptus* species in consecutive three years of the study period in Decha district of Kaffa zone, south-west Ethiopia.

Treatments	Biomass Yield (t/ha) (Mean ± SD)			Plant height (m) (Mean ± SD)		
	Year			Year		
	2014	2015	2016	2014	2015	2016
T_1 (Sole maize)	59.6 ± 9.7	80.3 ± 5.9	33.2 ± 7.2a	2.2 ± 0.25	2.7 ± 0.26	2.2 ± 0.16a
T_2 (*E. citriodora* with maize)	59.4 ± 5.4	69.3 ± 14.3	25 ± 7.8bc	2.3 ± 0.22	2.7 ± 0.28	2.1 ± 0.16ab
T_3(*E. camaldulensis* with maize)	70.9 ± 1.4	84.6 ± 9.8	29.6 ± 1.6ab	2.4 ± 0.14	2.8 ± 0.16	1.8 ± 0.1b
T_4(*E. grandis* with maize)	55.3 ± 6.0	71.7 ± 10.9	23.6 ± 6.6bc	2.2 ± 0.20	2.7 ± 0.17	2 ± 0.19ab
T_5(*E. saligna* with maize)	50.3 ± 7.9	47.4 ± 9.4	22.6 ± 8.9c	2.2 ± 0.31	2.4 ± 0.22	1.9 ± 0.29b
CV (%)	14.9	19.5	14	8.7	8.8	7.3
$LSD_{(p = 0.05)}$	NS	NS	6.8	NS	NS	0.26

Note: Mean values with different letters are statistically different at α = 0.05.

Eucalyptus saligna and *Eucalyptus grandis* significantly reduced maize biomass yield in the third year of intercropping when compared to other treatments (Table 3).

No significant effect of *E. camaldulensis* on grain and biomass yield was recorded across all studied seasons. A similar result was reported by Alebachew et al. (2021). namely that *E. camaldulensis* is well suited for growing in arable fields and that intercropping maize with trees planted at 5 × 5 m gave satisfactory yields. (Ceccon 2008) has also reported positive results when intercropping *E. camaldulensis* with crops. However, maize yield and yield parameters suppression were recorded up to a distance of 20 m away from *E. camaldulensis* stand in Western Amhara, Ethiopia (Abdoulaye et al. 2012).

After the third year of cropping, maize intercropping was no longer possible in all *Eucalyptus* species due to canopy closure. During the first year of cropping, grain yield, biomass, and other growth parameters were not significantly affected ($p \leq 0.05$). This may be attributed to the early growth stage of the trees, during which their competition for above- and below-ground resources with understory crops is still limited (Laclau et al. 2003).

The study examined nutrient dynamics in short-rotation *Eucalyptus* and identified two distinct growth phases. The first is the juvenile phase, lasting until canopy closure, during which nutrient uptake from the soil adequately meets the trees' requirements. The second phase is characterized by intensive nutrient

recycling. The second and third cropping season show a significant difference among the treatments in both maize yield and yield component ($p \leq 0.05$). Particularly in the third year of the cropping season, maize grain yield in the monoculture system was significantly higher than intercropped maize yield.

Tree growth performance in the hedgerow agroforestry practice

The statistical comparison showed that DBH and height growth of *Eucalyptus saligna* and *Eucalyptus grandis* were significantly ($p < 0.05$) higher than *Eucalyptus camaldulensis* and *Eucalyptus citriodora* across all years (Table 4, Fig. 3).

The highest mean annual diameter and height increment was observed for *Eucalyptus saligna* (3.48 cm and 3.78 m) followed by *Eucalyptus grandis* (3.44 cm and 3.65 m). The lowest values were recorded by *Eucalyptus camaldulensis* and *Eucalyptus citriodora* (Fig. 3). A consistent result with the present study was reported by Delgado-Matas and Pukkala 2011 that both *E. grandis* and *E. saligna* showed excellent performance among six studied eucalyptus species in Angola.

Table 4. Height and diameter at breast height of *Eucalyptus* species in three consecutive years of study.

Eucalyptus species	Tree height (m) (Mean ± SD)			DBH (cm) (Mean ± SD)		
	Year			Year		
	2014	2015	2016	2014	2015	2016
E. saligna	4.7 ± 0.21a	10.5 ± 0.92a	15.1 ± 1.4a	3.5 ± 0.2a	8.8 ± 0.4a	13.9 ± 0.52a
E. grandis	4.5 ± 0.62a	9.8 ± 0.71a	14.6 ± 0.65a	3.3 ± 0.59a	8.5 ± 0.19a	13.6 ± 1.1a
E. citriodora	3.3 ± 0.28b	7.5 ± 0.59b	10.5 ± 0.57b	2.5 ± 0.23b	7.1 ± 0.11b	11.3 ± 0.31b
E. camaldulensis	2.9 ± 0.25b	7.4 ± 0.64b	10.4 ± 0.73b	2.2 ± 0.22b	7.1 ± 0.63b	11.3 ± 0.44b
CV (%)	9.7	8.2	7.1	12	4.9	5.2
$LSD_{(p = 0.05)}$	0.7	1.4	1.7	0.6	0.7	1.2

Note: DBH = diameter at breast height in centimeters, mean values with different letters are statistically different at α 0.05.

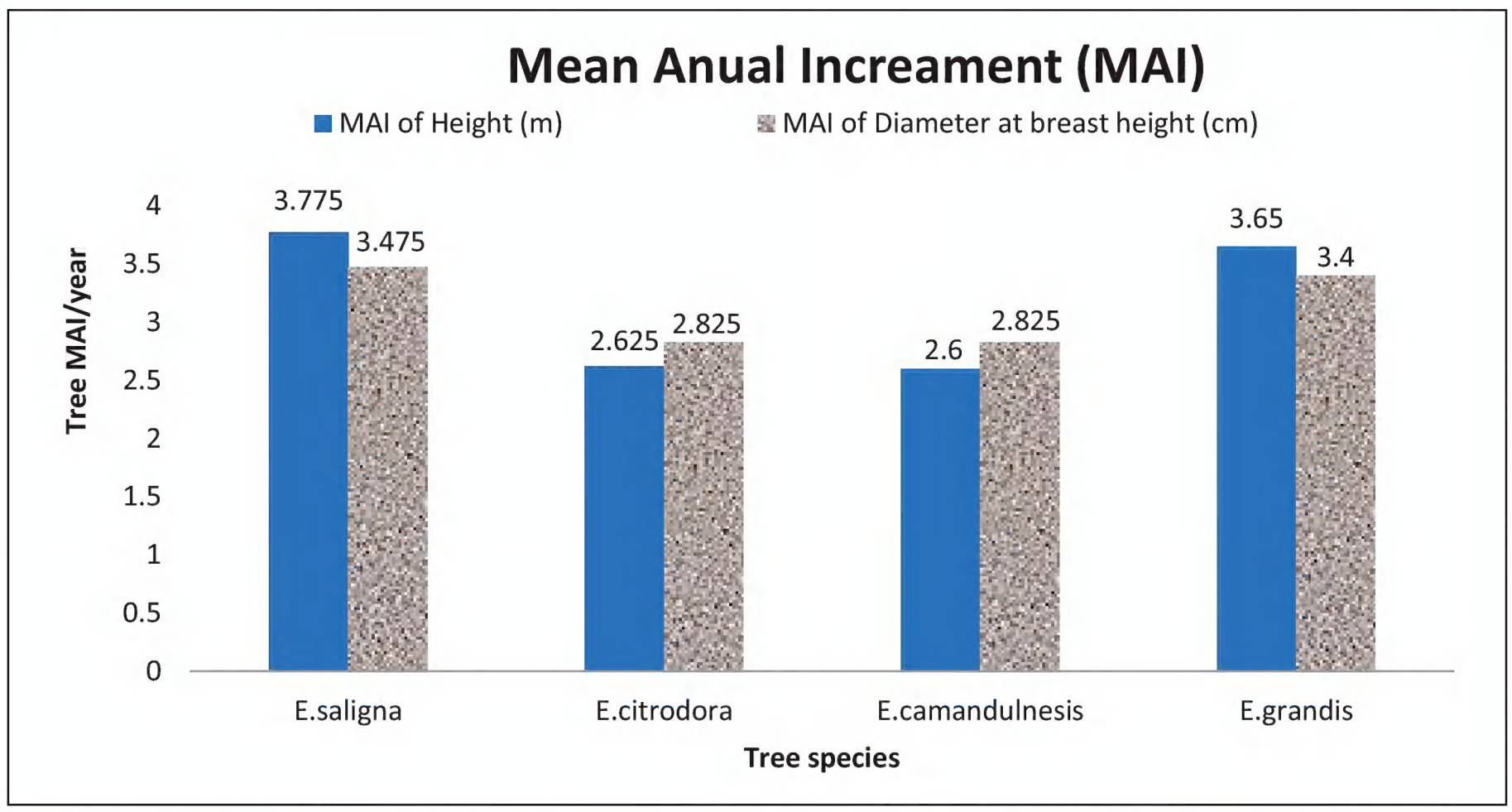

Figure 3. Mean annual height and diam increment of *Eucalyptus* species planted on hedgerow in Decha district of Kaffa zone, southwest Ethiopia.

Tree basal area and intercrop yield

The results of Nissen and Midmore 2002 have suggested using the stand basal area as a simple parameter to evaluate competitiveness in intercropping systems and to provide an estimation of the economic value of the tree component. Analysis of Pearson Correlation in the present study revealed that basal area and maize grain yield were negatively correlated (Fig. 4). As the basal area of *E. saligna* increased from 343.3 m^2/ha in 2014 to 5107 m^2/ha in 2016, maize grain yield declined by 0.49 t/ha, equivalent to approximately 27.5%**,** showing the competitive effect of the tree on maize production (Table 5). Similar results were reported by Bertomeu 2012 that the increment in the basal area of *Eucalyptus deglupta* resulted in a reduction of maize grain yield by 40%.

Effect of *Eucalyptus* leaf extract on seed germination and seedling growth of maize

The effect of these *Eucalyptus* trees' leaf extracts on germination percentage, fresh weight, and dry weight of maize was recorded and summarized (Table 6). The results of each tree species were discussed separately.

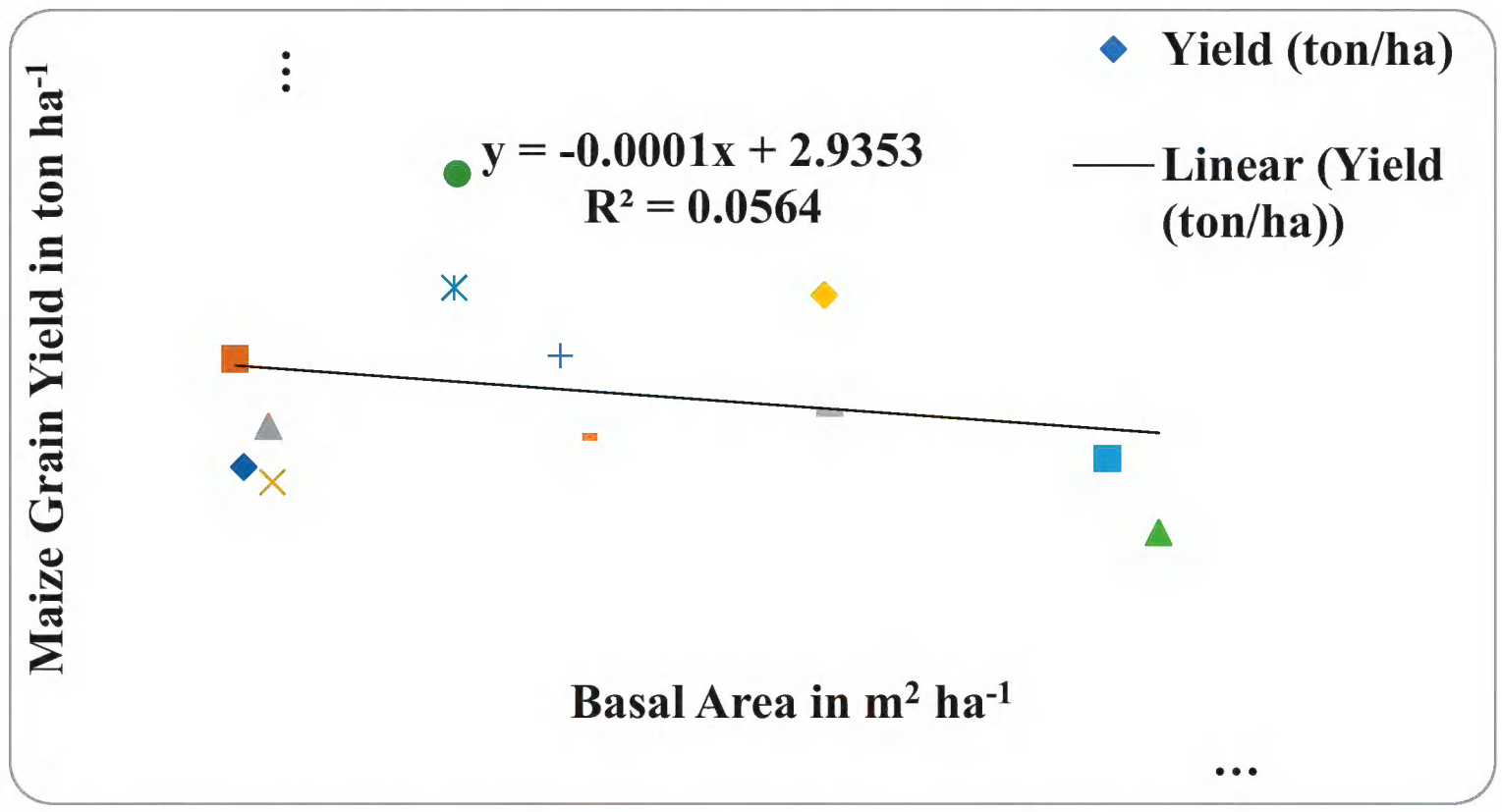

Figure 4. Correlation between *Eucalyptus* tree basal area and maize grain yield planted on hedgerow in Decha district of Kaffa zone, southwest Ethiopia.

Table 5. Basal area of *Eucalyptus* species over three consecutive years of study.

Eucalyptus species	Basal area (m^2/ha) (Mean ± SD)		
	Year		
	2014	2015	2016
E. saligna	343 ± 30.8a	2017 ± 181.4a	5107 ± 383.4a
E. grandis	323 ± 109.3a	1893 ± 84.7a	4830 ± 776.3a
E. citriodora	190 ± 34.9b	1320 ± 42.4b	3340 ± 180.3b
E. camaldulensis	143 ± 44.7b	1337 ± 235.7b	3310 ± 261.8b
CV (%)	25.2	9.5	11.1
$LSD_{(p = 0.05)}$	117	293	870

Note: Mean values with different letters are statistically different at α 0.05.

Table 6. Effect of *Eucalyptus* leaf extract on seed germination and seedling growth of maize in Decha district of Kaffa zone, south-west Ethiopia.

0.8	G (%)	SL (cm)	RL (cm)	SFW (g)	RFW (g)	SDW (g)	RDW (g)	CD (cm)
Control	58 ± 3.1e	22.5 ± 1.8c	67.1 ± 3.8b	3.0 ± 0.6b	4.0 ± 0.9a	0.41 ± 0.2	0.38 ± 0.2	0.22 ± 0.08b
E. citriodora	97 ± 2.9a	26.8 ± 3.6b	78.2 ± 2a	4.5 ± 0.5a	3.3 ± 0.4ab	0.63 ± 0.2	0.28 ± 0.1	0.42 ± 0.18a
E. camaldulensis	76 ± 2.5d	29.3 ± 2ab	61.9 ± 1.4c	4.8 ± 0.9a	3.2 ± 0.5ab	0.59 ± 0.3	0.26 ± 0.1	0.32 ± 0.08ab
E. grandis	82 ± 2.5c	32.1 ± 2.9a	51.5 ± 3.2d	4.1 ± 0.5a	2.3 ± 1b	0.49 ± 0.2	0.29 ± 0.1	0.28 ± 0.15ab
E. saligna	89 ± 4.1b	30.4 ± 2.3a	41.5 ± 2.8e	4.9 ± 0.9a	2.2 ± 0.4b	0.80 ± 0.5	0.29 ± 0.1	0.42 ± 0.1a
CV (%)	**30**	**9.88**	**4.8**	**18.58**	**24.35**	***33.07***	**32.05**	**30.5**
$LSD_{(P = 0.05)}$	**5.008**	**4.3**	**4.45**	**1.17**	**1.11**	**NS**	**NS**	**0.16**

Note: SL = shoot length in cm, RL = root length in cm, SFW = shoot fresh weight in gram, RFW = root fresh weight in gram, SDW = Shoot dry weight in gram, RDW = root dry weight in gram, CD = collar diameter in cm.

Germination percentage

The results revealed that *Eucalyptus* aqueous extract application significantly stimulated seed germination over water-applied treatment (Table 6). The increase in germination percentage was found from 18–39% as compared to the control and the more stimulating effect was recorded on the pot irrigated by *Eucalyptus citriodora* leaf extract followed by *Eucalyptus saligna*. Whereas a significantly lower germination percentage was recorded on the pot irrigated with water (Table 6). Inconsistent study results were reported by different scholars. Similar to the present study, the stimulatory effect of eucalyptus tree species was reported by Nadir et al. (2018) who noted that a higher germination percentage of crops was recorded under eucalyptus trees than in open land. Furthermore, the beneficial effect of eucalyptus on the germination of wheat and cowpea was also reported by Blaise et al. (1997). On the other hand, Espinosa-García et al. 2008; Abugre et al. (2011) revealed that *Eucalyptus grandis* had no allelopathic effect on germination of maize. On the contrary, various studies revealed that extracts of eucalyptus inhibited the germination of some crops (Lisanework and Michelsen 1993; Hassan et al. 2012; Khan et al. 2023).

Shoot and root fresh weight

The study result revealed that the effect of aqueous extracts of all studied *Eucalyptus* was found to be stimulatory regarding the shoot fresh weight of maize seedlings as compared to the control (Table 6). The results regarding root fresh weight showed that aqueous extract of *Eucalyptus saligna* and *Eucalyptus grandis* induced inhibitory effects on the root fresh weight of maize plant as compared to the control.

Shoot and root dry weight

The effect of aqueous extract was found to be non-significant regarding shoot and root dry weight (Table 6). Contrary to this study, Akram et al. (2017) reported the inhibitory effect of *Eucalyptus camaldulensis* on the root dry weight of maize.

Shoot and root growth

The aqueous extract of *Eucalyptus* was found to be stimulatory regarding shoot growth (Table 6). Similarly, the application of leaf extract of

Eucalyptus citriodora induced a stimulatory effect on root length and collar diameter growth of maize seedlings. This may be due to the nature of chemicals in the extract which might have stimulated the production and synthesis of growth hormones such as auxins (Abugre et al. 2011). The allelochemicals at low concentrations may act as plant growth regulators (Purl and Khara 1991; Madurai Muthu and Sheeba 2014). The remaining three eucalyptus tree species Vis *E. camaldulensis*, *E. grandis* and *E. saligna* induced the inhibitory effect on the root length growth of maize seedlings as compared to the control. Similar to the present study, Abugre et al. (2011) observed the inhibitory effect of *E. grandis* (leaf and root extract) on the root growth of maize seedlings as compared to the control. Phenolic acids and volatile oils released from the leaves, bark and roots of certain *Eucalyptus* spp. have deleterious effects on other plant species (Zhang and Fu 2009; Khan et al. 2023).

Even though the yield of maize was higher in monocropping as compared to intercropping with *Eucalyptus* tree species, in the concept of agroforestry there is the possibility to produce maize crops in a eucalyptus plantation in the early stage of tree growth. In addition, if the smallholder farmers wish to process more wood products from the unit area it is important to intercrop maize with *Eucalyptus grandis* and *Eucalyptus saligna* rather than others. Also, based on this research, we found that the extract of *Eucalyptus* species showed no inhibitory effect on the germination of maize seeds, suggesting that the use of additional seed to compensate for potential allelopathic effects of *Eucalyptus* species may be unnecessary beyond the recommended seeding rate per hectare

Conclusions

The overall yield of maize grown under *Eucalyptus camaldulensis* revealed itself to be a better product next to mono-cropping than other *Eucalyptus* species. Yield reduction was noticed on maize grown under *Eucalyptus saligna* and *Eucalyptus grandis* hedgerow. While *Eucalyptus saligna* and *Eucalyptus grandis* showed a better growth performance than *Eucalyptus citriodora* and *Eucalyptus camaldulensis*. Maize grain yield was affected by tree age and size of the *Eucalyptus* species which tends to decrease with increasing the basal area. Evaluation of the allelopathic effect of eucalyptus tree species on maize seedling growth revealed a stimulatory effect on germination percentage, shoot length, and shoot fresh weight, but an inhibitory effect on root length and fresh weight. Therefore, growing *Eucalyptus camaldulensis* with maize intercropping, in hedge row arrangement with enough spacing between hedgerows, can provide both wood and food products from a unit land area for short rotation. But if the objective of the farmer is to get high volume of wood than maize yields, it is advisable to grow maize crops in the hedgerow of *Eucalyptus saligna* and *Eucalyptus grandis* with different tree management measures that are expected to minimize above and below-ground competition to annual crops. The costs and benefits of planting need to be a careful assessment based on detailed studies giving due consideration to both ecological and socio-economic needs. We recommend farmers should intercrop maize with well-spaced eucalyptus hedgerows using *Eucalyptus camaldulensis* to balance food and wood production, or *Eucalyptus saligna* and *Eucalyptus grandis* when prioritizing wood yield supported by proper tree management and cost-benefit evaluation.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Use of AI

No use of AI was reported.

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Author contributions

Asrat Alemayhu; Follow up, Data collection and final write-up, Kebede Gizachew, Data collection and paper editing., Getahun Yakob, Proposal initiation and paper editing., Bedilu G/Kidan, Data collection., Henok Tsegaye, Data collection.

Data availability

All of the data that support the findings of this study are available in the main text.

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